REMARKS

Claims 1-8 are pending in this application.

Reconsideration and allowance of the present application based on the following remarks is respectfully requested.

Claim Objections

Claim 7 has been objected to because the phrase "on which a substrate" is repeated in line 2. Accordingly, Applicants have amended claim 7 and deleted the second phrase "on which a substrate." Therefore, Applicants respectfully request withdrawal of the Objection to claim 7.

Claim Rejections - 35 USC § 102

Claims 1-8 have been rejected under 35 U.S.C. § 102(e) over Omi et al., JP 2000-040695.

In response to the arguments filed May 30, 2003, the Examiner states that no translation of the priority document is found in the application.

As the Examiner noted in the Response to Arguments filed May 30, 2003, Applicants have submitted a certified copy of the priority document, Japanese Patent Application 11-375974. To perfect Applicants' claim of priority, Applicants are submitting herewith an English translation of the certified priority document. Therefore, the priority date of the present application is November 25, 1999 as now perfected. Consequently, the Omi et al. (JP 2000-040695A) reference which has a date of publication of February 8, 2000 is precluded from use as a prior art.

Therefore, Applicants respectfully request that the rejection of claims 1-8 under § 102(e) be withdrawn.

Claims 1 and 3-6 have been rejected under 35 U.S.C. § 102(e) as being anticipated by Shan et al. (US Patent No. 6,232,236). Applicants respectfully traverse this rejection for at least the following reasons.

Claim 1 recites, *inter-alia*, "an auxiliary electrode provided on an outer periphery of said first electrode to excite plasma in a vicinity of the auxiliary electrode, wherein electrons

in the plasma drift from a front surface of said auxiliary electrode to a back surface thereof and from the back surface of said auxiliary electrode to the front surface thereof." By using the auxiliary electrode, the generation of plasma density can be equalized and the surface of the substrate under process is thus exposed to a uniform plasma distribution. As a result, a higher quality material deposition or etching on the surface of the substrate is obtained.

In contrast, the process kit 220 of Shan et al. has a depending extension 226 (see col. 4, lines 9-12). The process kit 220 of Shan et al. has an "L-like-shape." The process kit 220 of Shan et al. is merely connected to RF power supply 242 to sustain a secondary plasma 235 proximate the top surface 222 of the process kit 220. The secondary plasma 235 provides (as shown by the arrows in Figure 2 of Shan et al.) electrons 237 to the primary plasma 230 to produce additional ions. Thus, the electrons 237 trajectory goes straight from secondary plasma 235 to primary plasma 230. This is completely different from "the electrons drift from a front surface of said auxiliary electrode to a back surface thereof and from the back surface of said auxiliary electrode to the front surface thereof," as recited in claim 1.

In fact, due to the structure of the process kit 220 in Shan et al., the electrons cannot drift to the bottom surface 224 of the process kit 220 because the presence of extension 226 can hinder the movement of electrons. Furthermore, because the bottom surface 224 is in direct contact with the upper surface 217 of the flange 216 (see Figure 2 and related description in Shan et al.), the electrons cannot drift to the bottom surface, i.e. to the back surface, 224. Consequently, contrary to the Examiner's contention, Shan et al. does not disclose, teach or suggest, *inter-alia*, "an auxiliary electrode provided on an outer periphery of said first electrode to excite plasma in a vicinity of the auxiliary electrode, wherein electrons in the plasma drift from a front surface of said auxiliary electrode to a back surface thereof and from the back surface of said auxiliary electrode to the front surface thereof."

Therefore, Applicants respectfully submit that claim 1, and claims 3-6 which are dependent directly or indirectly from claim 1, are patentable and respectfully request that the rejection of claims 1 and 3-6 under § 102(e) be withdrawn.

<u>Claim Rejections - 35 USC § 103</u>

Claims 2 and 8 have been rejected under 35 U.S.C. § 103(a) as being unpatentable over Shan et al. (US Patent No. 6,232,236) in view of Dornfest et al. (US Patent No. 5,949,409).

Claim 2 is dependent from claim 1. Therefore, for at least the reasons provided above with regard to claim 1, claim 2 is patentable over Shan et al. Furthermore, as conceded in the Office Action, Shan et al. does not disclose covering the auxiliary electrode with insulating material.

Dornfest et al. fails to overcome the deficiencies of Shan et al. noted above with regard to claim 1. Consequently, neither Shan et al. nor Dornfest et al., alone or in combination, disclose, teach or suggest the subject matter recited in claim 2.

Claim 8 recites, *inter-alia*, "an auxiliary electrode provided on an outer periphery of said first electrode to excite plasma in a vicinity of the auxiliary electrode, the front surface of said auxiliary electrode being covered by an insulating material, wherein electrons in the plasma drift from a front surface of said auxiliary electrode to a back surface thereof and from the back surface of said auxiliary electrode to the front surface thereof."

Similarly, for at least the reasons presented above with regard to claim 1, Shan et al. does not disclose, teach or suggest "an auxiliary electrode provided on an outer periphery of said first electrode to excite plasma in a vicinity of the auxiliary electrode, the front surface of said auxiliary electrode being covered by an insulating material, wherein electrons in the plasma drift from a front surface of said auxiliary electrode to a back surface thereof and from the back surface of said auxiliary electrode to the front surface thereof."

Dornfest et al. does not overcome the deficiencies of Shan et al. Consequently, neither Shan et al. nor Dornfest et al., alone or in combination, disclose, teach or suggest the subject matter recited in claim 8.

Therefore, Applicants respectfully submit that claims 2 and 8 are patentable and respectfully request that the rejection of claims 2 and 8 under § 103(a) be withdrawn.

Claim 7 has been rejected under 35 U.S.C. § 103(a) as being unpatentable over Shan et al. (US Patent No. 6,232,236) in view of Ohmi et al. (WO 98/39500). Applicants respectfully traverse this rejection for at least the following reasons.

Claim 7 recites, *inter-alia*, "applying a static magnetic field to a surface of the substrate to which the plasma process is applied; exciting plasma on at least a back surface of the auxiliary electrode; and causing electrons in the plasma to drift from a front surface of said auxiliary electrode to the back surface thereof and from the back surface of said auxiliary electrode to the front surface thereof."

For at least the reasons provided above with respect to claim 1, Applicants submit that Shan et al. does not disclose, teach or suggest "causing electrons in the plasma to drift from a front surface of said auxiliary electrode to the back surface thereof and from the back surface of said auxiliary electrode to the front surface thereof." Furthermore, as conceded in the Office Action, Shan et al. does not disclose or suggest a plasma processing method including applying a static magnetic field.

Ohmi et al. merely discloses a plasma etching device which has an auxiliary electrode and a magnetic device for applying a magnetic field to enable generation of uniform density plasma. The auxiliary electrode of Ohmi et al. is attached to the electrode substrate holder (see, Figure 1 in Ohmi et al.). The back surface of the auxiliary electrode is in contact with the surface of the chuck. Hence, the electrons generated in the plasma and guided by the magnetic field cannot drift from the front surface of the auxiliary electrode to the back surface of the auxiliary electrode because the back surface of the auxiliary electrode is not accessible to the flow of electrons. Consequently, neither Shan et al. nor Ohmi et al., alone or in combination, disclose, teach or suggest the subject matter recited in claim 7.

Therefore, Applicants respectfully submit that claim 7 is patentable and respectfully request that the rejection of claim 7 under § 103(a) be withdrawn.

Claims 1, 3-5 have been rejected under U.S.C § 103(a) as being unpatentable over Asamaki et al. (US Patent No. 4,950,956) in view of Okumura et al. (US Patent No. 6,297,165). Applicants respectfully traverse this rejection for at least the following reasons.

Claim 1 recites a plasma processing apparatus comprising, among other elements, an auxiliary electrode provided on an outer periphery of a first electrode to excite plasma in a vicinity of the auxiliary electrode and a magnetic field generator configured to apply a magnetic field to a surface of the substrate to which the plasma process is applied, wherein electrons in the plasma drift from a front surface of the auxiliary electrode to a back surface thereof and from the back surface of the auxiliary electrode to the front surface thereof.

As conceded in the Office Action, Asamaki et al. does not disclose, teach or suggest an auxiliary electrode provided on an outer periphery of the first electrode to excite plasma by the auxiliary electrode so as to cause electrons in the plasma to drift from a front surface to a back surface of the auxiliary electrode and from the back surface to the front surface of the auxiliary electrode.

Okumura et al. merely teaches a ring-form voltage monitoring conductor 11 that is configured to monitor the self-bias potential generated in the substrate 8. The Okumura et al. patent is directed to etching and cleaning methods in which an end of an etching process or cleaning process is determined based on the self-bias potential of the substrate, which is monitored by the voltage monitoring conductor 11 (See Figure 2 and col. 4, line 40 through col. 5, line 38 of Okumura et al.). In Okumura et al., a high-frequency electric power is supplied to the substrate electrode 7 and to voltage monitoring conductor 11. When high-frequency electric power is supplied to a solid material in contact with a plasma, negative DC potentials are generated in the solid material. This DC potential is called self-biasing potential. Since the self-biasing potential on substrate 8 cannot be measured directly, measuring the self-biasing potential on conductor 11 is used as a proxy for the self-biasing potential on substrate 8. Thus, in order to replicate the self-biasing potential on the substrate 8, the conductor 11 is driven with a high-frequency electric in the same way as the substrate electrode 7. In addition to applying a high-frequency electric power to the substrate electrode 7, a high DC voltage is also applied to the substrate electrode 7 to hold the substrate 8 on the chuck electrode 7.

There is no suggestion or motivation in Okumura et al. that by applying an appropriate magnetic field, the electrons will drift as recited in claim 1. Okumura et al. does not teach or suggest producing a magnetic field capable of generating an electron drift, wherein the electrons are caused to drift parallel to the front and back surfaces of the auxiliary electrode. In fact, Okumura et al. teaches away from controlling the drift of electrons as recited in claim 1 by specifically teaching that the electrode 11 is <u>used to measure</u> the self-biasing potential on substrate 8.

Furthermore, even if one were to modify the apparatus of Asamaki et al. by incorporating the structure of Okumura et al. and apply a magnetic field to the structure of Okumura et al., which Applicants do not concede, the electrons in the plasma would not drift as recited in claim 1 because of the presence of the high DC voltage in the substrate electrode 7. Indeed, the flow of electrons would be perturbed by the high DC potential field produced in the vicinity of the back surface of substrate electrode 7 and this will hinder the flow the electrons. Moreover, the magnetic field generated in the apparatus of Asamaki et al. is a rotating magnetic field, which is intermittently pulsed. Thus, the magnetic field in the apparatus of Asamaki et al. is completely different from the <u>static</u> magnetic field recited in

claim 1. Consequently, neither Asamaki et al. nor Okumura et al., alone or in combination, disclose, teach or suggest the subject matter recited in claim 1.

Therefore, Applicants respectfully submit that claim 1, and claims 3-5 which are directly or indirectly dependent from claim 1, are patentable and respectfully request that the rejection of claims 1 and 3-5 under § 103(a) be withdrawn.

Claims 2 and 8 have been rejected under U.S.C § 103(a) as being unpatentable over Asamaki et al. (US Patent No. 4,950,956) in view of Okumura et al. (US Patent No. 6,297,165) and further in view of Dornfest et al. (US patent No. 5,949,409). Applicants respectfully traverse this rejection for at least the following reasons.

Claim 2 is dependent from claim 1. Therefore, for at least the reasons presented above with regard to claim 1, Applicants respectfully submit that claim 2 is patentable over Asamaki et al. in view of Okumura et al. Dornfest et al. fails to overcome the deficiencies noted above in Asamaki et al. and Okumura et al. Therefore, Applicants respectfully submit that claim 2 is patentable.

Claim 8 recites, *inter-alia*, "an auxiliary electrode provided on an outer periphery of said first electrode to excite plasma in a vicinity of the auxiliary electrode, the front surface of said auxiliary electrode being covered by an insulating material, wherein electrons in the plasma drift from a front surface of said auxiliary electrode to a back surface thereof and from the back surface of said auxiliary electrode to the front surface thereof."

Similarly, for at least the reasons provided above with regard to claim 1, Applicants respectfully submit that claim 8 is patentable over Asamaki et al. in view of Okumura et al. Dornfest et al. fails to overcome the deficiencies noted above in Asamaki et al. and Okumura et al. Therefore, Applicants respectfully submit that claim 8 is patentable.

Therefore, Applicants respectfully request that the rejection of claims 2 and 8 under § 103(a) be withdrawn.

Claim 6 has been rejected under U.S.C § 103(a) as being unpatentable over Asamaki et al. (US Patent No. 4,950,956) in view of Okumura et al. (US Patent No. 6,297,165) and further in view of Shan et al. (US patent No. 6,232,236). Applicants respectfully traverse this rejection for at least the following reasons.

Claim 6 is directly or indirectly dependent from claim 1. Therefore, for at least the reasons presented above with regard to claim 1, Applicants respectfully submit that claim 6 is patentable over Asamaki et al. in view of Okumura et al. Shan et al. fails to overcome the deficiencies noted above in Asamaki et al. and Okumura et al. Therefore, Applicants respectfully submit that claim 6 is patentable and respectfully request that the rejection of claim 6 under § 103(a) be withdrawn.

Claim 7 has been rejected under U.S.C § 103(a) as being unpatentable over Asamaki et al. (US Patent No. 4,950,956) in view of Okumura et al. (US Patent No. 6,297,165) and further in view of Ohmi et al. (WO 98/39500). Applicants respectfully traverse this rejection for at least the following reasons.

Claim 7 recites, *inter-alia*, "applying a static magnetic field to a surface of the substrate to which the plasma process is applied; exciting plasma on at least a back surface of the auxiliary electrode; and causing electrons in the plasma to drift from a front surface of said auxiliary electrode to the back surface thereof and from the back surface of said auxiliary electrode to the front surface thereof."

For at least the reasons presented above with regard to claim 1, neither Asamaki et al. nor Okumura et al., alone or in combination, disclose, teach or suggest the subject matter recited in claim 7. Moreover, there is no suggestion or motivation to use a static magnetic field in the apparatus of Asamaki et al. because according to Asamaki et al. the rotating magnetic field provides the desired processing characteristics (see the abstract of Asamaki et al.). Furthermore, even if one were to apply a static magnetic field to the apparatus of Asamaki et al. modified by Okumura et al., which Applicants do not concede, the electrons would not drift in the manner recited in claim 7 for at least the reasons provided above with regard to claim 1. Consequently, none of Asamaki et al., Okumura et al. and Ohmi et al. disclose, teach or suggest, alone or in combination, the subject matter recited in claim 7.

Therefore, Applicants respectfully submit that claim 7 is patentable and respectfully request that the rejection of claim 7 under § 103(a) be withdrawn.

CONCLUSION

In view of the foregoing, the claims are now in form for allowance, and such action is hereby solicited. If any point remains in issue which the Examiner feels may be best resolved through a personal or telephone interview, he is kindly requested to contact the undersigned at the telephone number listed below.

All objections and rejections having been addressed, it is respectfully submitted that the present application is in a condition for allowance and a Notice to that effect is earnestly solicited.

Respectfully submitted,
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(Lists of Submitted Documents)	
(Document Name)	Specification 1
(Document Name)	Drawing 1
(Document Name)	Abstract 1

[Name of Document] SPECIFICATION

[Title of Invention] PLASMA PROCESSING APPARATUS AND PROCESS USING PLASMA APPARATUS

[Claims]

1. A plasma processing apparatus comprising a first electrode on which a substrate subjected to a plasma process is placed and magnetic field applying means for applying a magnetic field to a surface of the substrate to which the plasma process is applied, characterized in that:

an auxiliary electrode is provided on an outer periphery of said first electrode to excite plasma by the auxiliary electrode so as to cause electrons in the plasma to drift from a front surface to a back surface of said auxiliary electrode and from the back surface to the front surface of said auxiliary electrode.

2. The plasma processing apparatus as claimed in claim 1, characterized in that the front surface of said auxiliary electrode is covered by an insulating material.

3. The plasma processing apparatus as claimed in claim 1 or 2, characterized in that a level of a surface of the substrate placed on said first electrode and a level of the front surface of said auxiliary electrode are equal to each other or within ±2 mm.

4. The plasma processing apparatus as claimed in any one of claims 1 through 3, characterized in that said magnetic field applying means comprises a dipole ring-magnet.

5. The plasma processing apparatus as claimed in any one of claims 1 through 4, characterized in that a frequency f1 of a radio frequency applied to said first electrode and a frequency f2 of a radio frequency applied to said auxiliary electrode are equal to each other and phases thereof are different from each other.

6. The plasma processing apparatus as claimed in any one of claims 1 through 4, characterized in that a frequency f2 of a radio frequency applied to said auxiliary electrode is higher than a frequency f1 of a radio frequency applied to said first electrode (f2>f1).

7. A process using a plasma processing apparatus comprising a first electrode on which a substrate subjected to a plasma process is placed and magnetic field applying means for applying a magnetic field to a surface of the substrate to which the plasma process is applied, characterized by:

exciting plasma on a back surface of an auxiliary electrode provided on an outer periphery of said first electrode, and causing electrons in the plasma to drift from a front surface to the back surface of said auxiliary electrode and from the back surface to the front surface of said auxiliary electrode.

[Detailed Description of the Invention]

[Technical Field of the Invention]

The present invention relates to a plasma processing apparatus and a plasma processing method implemented by the plasma processing apparatus.

[The Conventional Art]

With the enlargement of chip size in DRAM, MPU and the like, there is a tendency for the silicon substrate used as a base for the above chips to also be increased in diameter. Etching of a silicone oxidization film or a polycrystalline silicon film is one of the most important process in production of a semiconductor, and plasma etching has been used as such etching. In order to form a fine pattern of 1.0 μm or less by plasma etching, plasma having an ion current density of 1 mA/cm^2 or more and an electron density of 1 10 cm^{-3} or more is required under a process pressure of 0.5 Pa or less. However, a conventionally used RIE apparatus of a parallel plate type was not able to generate plasma of such conditions.

In order to achieve the above-mentioned plasma performance, a plasma generating apparatus using a magnetic field has been developed. As an apparatus provided with such a plasma generating apparatus, Japanese Laid-Open Patent Application No. 6-37056 discloses a magnetron plasma etching apparatus using a dipole ring-magnet.

The magnetron plasma etching apparatus using a dipole-ring magnet is able to generate low pressure and high-density plasma. However, it is difficult to control the plasma generated on a substrate with high accuracy. That is, it becomes difficult to attain equalization of the plasma density on a substrate and equalization of a self-bias voltage by introducing a horizontal magnetic field on the substrate. As solution which attains equalization of plasma density and a self-bias voltage, a method of giving a slope to a magnetic field (Japanese Laid-Open Patent Application No. 62-21062) or a method of rotating a magnetic field introduced into a process space (Japanese Laid-Open Patent Application No. 61-208223) is suggested.

However, the solution suggested in Japanese Laid-Open Patent Application No. 62-21062 has a problem in that the optimum value of a slope magnetic field changes when a process pressure etc. is changed. Additionally, although the solution suggested in Japanese Laid-Open Patent Application No. 61-208223 apparently achieves equalization of plasma with respect to a substrate being processed, the mechanism for rotating the magnetic field is required, and there is a problem in that a miniaturization of the whole plasma apparatus is difficult.

In order to solve the above-mentioned problems, the method of equalizing plasma

by generating a uniform horizontal magnetic field by applying a high frequency electric power to an auxiliary electrode. In this solution method, an electron drift is generated in a direction opposite to an electron drift generated on a surface of the substrate placed on a lower electrode so as to promote circulation of electrons in the plasma, which prevents deviation of electrons. According to this solution, even if it is the case where process pressure etc. is changed, it is possible to attain equalization of plasma by changing the electric power of the radio frequency applied to the auxiliary electrode. Additionally, since it is not necessary to rotate a magnetic field, it is possible to attain a miniaturization of the plasma apparatus. However, in order to suppress a pressure distribution to less than several percent in the plasma apparatus which processes a substrate having a diameter of 300 mm or more, it is necessary to set a distance between the substrate and an upper electrode as 30 mm or more. In such a distance, diffusion of electrons which go from the surface of the substrate to the surface of the auxiliary electrode and from the auxiliary electrode to the surface of the substrate is suppressed. As a result, a movement of electrons is prevented and it is difficult to equalize the plasma.

Additionally, in the conventional sputter apparatus using a magnetron plasma source, an amount of reduction of a target material is uneven, and there is a problem in that an efficiency of use of the target is less than 50%. In order to solve such a problem, a method of using a generally uniform parallel magnetic field is considered. In such a case, it is necessary to rotate eh magnetic field or the substrate during a process. Therefore, the stress in a thin film formed on the substrate spreads to the entire substrate, and there is a problem in that the substrate is deformed due to relaxation of the stress during a machining process as a post process. Further, since the surface of the substrate is exposed to uneven plasma during film deposition process, a control of a film quality on the entire surface of the substrate is very difficult. For example, in a sputter apparatus which forms copper wiring, there is a problem in that the resistance of the formed copper wiring is as large as several times of a target value (theoretical value).

[Problem to be Solved by the Invention]

It is an object of the present invention to provide: a plasma etching apparatus, which can equalize the generated plasma density with respect to a surface of a substrate and a self-bias potential without rotating the magnetic field applying means while maintaining a pressure distribution on the substrate uniform independently of the configuration and distance of an upper electrode and can perform uniform etching without a charge-up damage to a substrate; a sputter apparatus, which can perform uniform sputtering on a substrate and does not generate a stress; and a plasma processing methods

using the above apparatuses.

[Means Used to Solve the Problem]

A first plasma processing apparatus according to the present invention comprises a first electrode on which a substrate subjected to a plasma process is placed and magnetic field applying means for applying a magnetic field to a surface of the substrate to which the plasma process is applied, the first plasma processing apparatus being characterized in that: an auxiliary electrode is provided on an outer periphery of the first electrode to excite plasma by the auxiliary electrode so as to cause electrons in the plasma to drift from a front surface to a back surface of the auxiliary electrode and from the back surface to the front surface of the auxiliary electrode.

[Embodiments]

In the following, embodiments of the present invention will be described with reference to figures. It is noted that the scope of the present invention is by no way limited to the embodiments described below.

[Embodiment 1]

A plasma processing apparatus according to embodiment 1 as shown in FIG.1 includes a first electrode 102 on which a substrate 101 subjected to a plasma process can be placed and magnetic field applying means 103 for applying a magnetic field to a surface of the substrate 101 to which the plasma process is applied, the plasma processing apparatus being characterized in that an auxiliary electrode 104 is provided on an outer periphery of the first electrode 102 to excite plasma by the auxiliary electrode 104 so as to cause electrons in the plasma to drift from a front surface 106 to a back surface 105 of the auxiliary electrode 104 and from the back surface 105 to the front surface 106 of the auxiliary electrode 104.

FIG. 1 is a structural diagram of a plasma processing apparatus according to a first embodiment of the present invention. In the plasma processing apparatus shown in FIG. 1, a substrate 101 to which a plasma process is applied is placed on a first electrode 102. A plasma process is performed on the substrate 101 by exciting plasma on the surface of the substrate 101. Also, the dipole ring-magnet 103 is provided. As a means to apply a magnetic field, although a permanent magnet or an electromagnet may be used, it is preferable to use a dipole ring-magnet when installation capacity, electric power consumption, magnetic field leakage, etc. are taken into consideration. An auxiliary electrode 104 is installed on an outer periphery of the first electrode 102. The auxiliary electrode may surround the entire periphery or a part of the periphery of the first electrode 102. The auxiliary electrode 104 is provided so as to excite plasma in the vicinity of the

back surface 105 and the front surface 106 thereof.

FIG 2 is a perspective view of the plasma processing apparatus of the present invention viewed from an upper N-pole direction of the applied magnetic field. This drawing shows the substrate 201, the first electrode 202 and the auxiliary electrode 203. An arrow 204 shows the drift of electrons to the front surface of the auxiliary electrode from the back surface of the auxiliary electrode, and an arrow 205 shows the drift of electrons to the back surface of the auxiliary electrode from the front surface of the auxiliary electrode. An arrow 206 indicated by the dotted line shows the drift of electrons in the vicinity of the back surface of the auxiliary electrode, and an arrow 207 shows the drift of electrons in the vicinity of the surface of the substrate and the front surface of the auxiliary electrode 104. The drift of electrons indicated by arrows 204, 205, 206 and 207 is generated by the interaction of a magnetic field or a magnetic field and substrate and a sheath electrode generated between the substrate and the auxiliary electrode.

In the conventional magnetron plasma apparatus, the drift of electrons shown by arrows 204, 205 and 206 hardly occurs, but only the drift of electrons shown by the arrow 207 occurs. For this reason, electrons in the plasma shift toward the W-pole, which results in generation of uneven plasma.

In the plasma processing apparatus according to the present embodiment, electrons generated by the surface of the substrate and the auxiliary electrode flow according to the electron drift on the surface of the substrate and the front surface of the auxiliary electrode (indicated by the arrow 207), the electron drift from the front surface to the back surface of the auxiliary electrode (indicated by the arrow 205), the electron drift on the back surface of the auxiliary electrode (indicated by the arrow 206), the electron drift from the back surface to the front surface of the auxiliary electrode (indicated by the arrow 204) and diffusion movement of electrons. According to the flow of electrons, electrons in the plasma are prevented from moving in a certain direction of the applied magnetic field, thereby achieving uniformization of the entire plasma.

[Embodiment 2]

In the present example, measurements of the self bias potential and the ion current intensity on the substrate and etching are conducted by a plasma etching apparatus as shown in FIG3 in a case where an auxiliary electrode is implemented causing the electrodes to drift from a front surface to a back surface of the auxiliary electrode and from the back surface to the front surface of the auxiliary electrode, and in a case where the auxiliary electrode is not implemented.

In FIG3, a chamber 301 that is made of aluminum, exhaust means 302

implements a turbo-molecular pump to depressurize the gas from inside the chamber 301 are shown. Additionally, C_4F_8, carbon monoxide, oxygen, and xenon are introduced by gas introduction means 303 so that the desired pressure can be set in the chamber 301. The combination of the gases is not limited to the above, and for example, a combination of gases C4F8, carbon monoxide, oxygen, argon may also be used. However, the combination C_4F_8, carbon monoxide, oxygen and xenon is preferable since they suppresses an excessive dissociation of gas and improve the etching characteristic. A first electrode 304 is connected to a radio frequency power supply 306 having a frequency of 13.56 MHz via a matching circuit 305. Although the frequency of the radio frequency power supply can also be set to 27.12 MHz or 40 MHz, a radio frequency of about 13.56 MHz is preferable, when etching of an oxidization film is performed, at which a self-bias potential of the plasma becomes large. In etching of an insulated film, it is preferable to set a high self-bias at an initial stage so as to etch at a high speed, and to set a low self-bias at an etching end stage. Accordingly, a damage of the background of the insulated film can be reduced. Also, a second electrode 307 is grounded. In the present example, a parallel plate type electrode is used as the second electrode 307; however, a plasma source electrode such as a multi-target type, a microwave excitation type, an electron cyclotron resonance type or an induction coupling type may be used. In order to improve the etching characteristic, the parallel plate type is preferable. A substrate 308 of silicon which is formed into a silicon oxidization film is placed on the surface of the first electrode 304. Magnetic field applying means 312 implements a dipole ring-magnet of 12 mT (120 Gausses).

FIG 4 is a plan view of the auxiliary electrode 309. Although a ring-shaped auxiliary electrode is used in the present embodiment, the auxiliary electrode 309 may be divided into four parts as shown in FIG 5. In this case, a distance 501 between the divided parts is preferably within 2 mm which is within an electron cycloid radius.

FIG 2 is a perspective view of the first electrode 304 and the auxiliary electrode 309 viewed from an upper N-pole direction of the applied magnetic field. As shown in FIG 2, by arranging the auxiliary electrode 205 on the outer periphery of the first electrode 206, the drift 203 of electrons from the E-pole to the W-pole in the applied magnetic field occurs on the surface of the substrate 207 and the front surface of the auxiliary electrode 205, and the drift 204 of electrons from the W-pole to the E-pole of the applied magnetic field occurs on the back surface of the auxiliary electrode 205. Moreover, on the W-pole side of the auxiliary electrode 205, the drift 201 of electrons from the back surface to the front surface occurs, and the drift of electrons from the back surface to the front surface

occurs on the E-pole side of the auxiliary electrode 205. By such electron drift, deviation of electrons can be prevented by the electron being caused to flow, and uniformization of plasma is achieved.

FIG 6 is a graph showing the self-bias potential measured in the plasma processing apparatus according to the present embodiment. Measurements were taken for the case where the auxiliary electrode is provided and the case where the auxiliary electrode is not provided. In the case where the auxiliary electrode is not provided, the structure is the same as that of a regular magnetron plasma apparatus. When the auxiliary electrode 104 was not provided, a self-bias potential difference of 20 V occurred between the E-pole side and the W-pole side on the substrate. However, self-bias potential difference was able to be set to 2 V by providing the auxiliary electrode on the outer periphery of the first electrode.

FIG 7 is a graph showing an ion current density measured in the plasma processing apparatus according to the present embodiment. When the auxiliary electrode was not provided, the ion current density dropped extremely on the E-pole side. However, like the present embodiment, by providing the auxiliary electrode on the outer periphery of the first electrode, the drop of the ion current on the side of the E-pole was able to be eliminated, and was able to achieve a uniform ion current density on the substrate.

Further, using the plasma etching apparatus according to the present invention, a silicon substrate was etched by introducing a mixed gas of C_4F_8, carbon monoxide, oxygen, and xenon into the process chamber and setting the chamber pressure to 5 Pa. The silicone substrate had a silicone oxidization film with a thickness of 1.6 micrometers formed on the surface thereof, and the diameter was 200 mm. When a radio frequency electric power of 1500 W was supplied to the first electrode 102 and a high frequency electric power of 200 W was supplied to the auxiliary electrode 104, the uniformity of the etching rate was ±2%.

[Embodiment 3]

In the present example, an application to a plasma sputtering film formation apparatus shown in FIG8 is described.

The chamber 801shown in FIG2 is made of aluminum, and a protective film is provided by forming an aluminum fluoride by applying a fluoride treatment to an inner surface thereof. The combination of materials is not limited the above, and it is preferable to form an inner wall which discharge an extremely small amount of gas such as water other than a process gas. Exhaust means 802 uses a turbo-molecular pump to depressurize the inside of the chamber 801. Additionally, gas introduction means 803 introduces argon

gas so as set a desired pressure in the chamber 801. The gas to be used is not limited to argon gas, and a mixture gas of xenon or krypton and oxygen may be used. Argon is preferable for a copper sputtering film deposition. A first electrode 804 is connected to the radio frequency power supply 806 having a frequency of 13.56 MHz via the matching circuit 805. The frequency of the radio frequency power supply 306 is not limited to this frequency and 27.12 MHz or 40 MHz may be used. As for sputtering, a frequency near 13.56 MHz is preferable at which the self-bias potential generated on the target surface becomes large. A substrate 807 as a copper target is attached to a surface of the first electrode. Although the copper target is used in the present embodiment, the target is not limited to copper and a material to be deposited can be attached as the target. The auxiliary electrode 808 is connected to the radio frequency power supply 810 having a frequency of 100 MHz via the matching circuit 809. Magnetic field applying means 811 uses a dipole ring-magnet of 12 mTs (120 Gausses). Also, a second electrode 812 is arranged in the position, which counters with first electrode. A silicon substrate 813 having a surface on which a silicone oxidization film is formed is placed on the second electrode 812. Additionally, the second electrode 812 is connected to a radio frequency power supply 815 having a frequency of 40 MHz via a matching circuit 814. The frequency of the radio frequency power supply 815 is not limited to this frequency, and 13.56 MHz or 27.12 MHz may be used. A higher frequency is preferable in order to increase the quantity of ions which irradiate the silicon substrate and to reduce the self-bias potential to be generated.

Copper sputtering was performed on the silicone substrate 813 by using the sputtering apparatus according to the present embodiment. Argon gas was introduced into the process chamber 108 and the pressure was set to 0.1 Pa. A radio frequency electric power of 1500 W was supplied to the first electrode 102, and a radio frequency electric power of 200 W was supplied to the auxiliary electrode 104. Consequently, a copper thin film was formed on the substrate 813, which film has no stress at all and has a film thickness uniformity of ±2% and a resistivity of 2.76 μΩ.

[Embodiment 4]

In the present example, investigation is made into the most effective frequency power applied to the auxiliary electrode for realizing uniformization of the self bias potential in the parallel plate type plasma etching apparatus as shown in FIG3 in a case where the surface of the auxiliary electrode is covered by an insulating material.

FIG 9 is a cross-sectional view of the auxiliary electrode. The auxiliary electrode 901 is made of an insulating material. In the present embodiment, although aluminum

nitride AlN is used as the insulating material, quartz, alumina, Teflon, polyimide, etc can be used as well. AlN is preferable because of a high thermal conductivity and a high plasma resistance.

Other features of the present embodiment are embodiment 1.

FIG 10 is a graph showing a radio frequency electric power applied to the auxiliary electrode, which can make a self-bias potential the most uniform in cases where a surface of the auxiliary electrode is covered or not covered by an insulating material.

When the surface of the auxiliary electrode was not covered by an insulator, the radio frequency electric power which can make a self-bias potential uniform was 200 W. On the other hand, it was 100 W when covered by an insulator.

Further, using the plasma etching apparatus according to the present embodiment, a silicon substrate was etched by introducing a mixed gas of C_4F_8, carbon monoxide, oxygen, and xenon into the chamber and setting the chamber pressure to 5 Pa. The silicone substrate had a silicone oxidization film with a thickness of 1.6 μm formed on the surface thereof, and the diameter was 200 mm. A radio frequency electric power of 1500 W was supplied to the first electrode 102 and a high frequency electric power of 200 W was supplied to the auxiliary electrode 104. As a result, the uniformity of the etching rate was ±2%.

By efficiently exciting the plasma on the back surface of the auxiliary electrode, the self bias potential can be made uniform with reduced frequency power and uniform etching can be realized.

[Embodiment 5]

In the present example, measurements are made of consumption rates of the inner wall of the chamber in a case where a radio frequency electric power having a frequency of 13.56 MHz, which is the same as the radio frequency electric power supplied to the first electrode, is supplied to the auxiliary electrode while varying the phase from 0 degree to 180 degrees in the flat plate type plasma etching apparatus shown in FIG4.

Other features of the present embodiment are identical to those of embodiment 1.

FIG 11 is a graph showing an amount of consumption of the inner wall of the process chamber.

After exciting plasma for 24 hours, change of the thickness in the inner wall of the process chamber was measured. In a case where a radio frequency of 13.56 MHz was applied to the first electrode 102 in phase of 0 degree, the thickness of the chamber decreased by 30 μm. On the other hand, when the radio frequency was applied with antiphase of 180 degrees, the thickness of the chamber decreased by 7 μm, and there was

least reduction of the thickness of the chamber.

Additionally, using the plasma etching apparatus according to the present embodiment, a silicon substrate was etched 300 times by introducing a mixed gas of C_4F_8, carbon monoxide, oxygen, and xenon into the process chamber and setting the pressure to 5 Pa, the silicone substrate having a silicone oxidization film with a thickness of 1.6 μm formed on the surface thereof and the diameter thereof being 200 mm. As a result, the consumption of the inner wall of the chamber was about 7 μm. In a conventional etching apparatus, the inner wall of the chamber is consumed about 50 μm in the same condition. Therefore, the consumption of the inner wall of the chamber was able to be reduced to 1/7 by using the plasma etching apparatus according to the present embodiment.

It was found from the above-mentioned results that by applying a radio frequency electric power having a frequency the same as that applied to the first electrode 102 but having a different phase to the auxiliary electrode, the inner wall of the chamber was prevented from being sputtered and was prevented from being sputtered at most at the antiphase since the plasma potential was reduced.

[Embodiment 6]

In the present example, the consumption rate of the auxiliary electrode was measured in a case where a radio frequency electric power having a frequency of 100 MHz which is higher than the frequency 13.56 MHz of the radio frequency electric power applied to the first electrode is applied to the auxiliary electrode. Other features are identical to embodiment 4.

Although the radio frequency electric powers of 13.56 MHz and 100 MHz were used in the present example, the present invention is not limited to this combination, and a radio frequency electric power of about 27 MHz may be applied to the first electrode and a radio frequency electric power of 60 MHz may be applied to the auxiliary electrode. Alternatively, radio frequency electric powers of 40 MHz and 80 MHz may be applied to the first electrode and the auxiliary electrode, respectively. Although there are various frequencies of the radio frequency electric power applied to the first electrode and the auxiliary electrode as mentioned above, a higher frequency is preferable for the radio frequency applied to the auxiliary electrode.

As shown in FIG.12, by increasing the frequency of the radio frequency power supply connected to the auxiliary electrode, the self-bias voltage generated in the auxiliary electrode can be suppressed, and the consumption of the auxiliary electrode due to sputtering can be reduced.

Additionally, using the plasma etching apparatus shown in FIG. 1, a silicon

substrate was etched 300 times by introducing a mixed gas of C_4F_8, carbon monoxide, oxygen, and xenon into the process chamber and setting the pressure to 5 Pa. The silicone substrate had a silicone oxidization film with a thickness of 1.6 μm formed on the surface thereof and the diameter thereof was 200 mm. As a result measurement of the amount of consumption of eh auxiliary electrode 104, the amount of consumption was about 5 mm. Since the amount of consumption in a conventional etching apparatus is 65 mm, the amount of consumption was reduced to 1/13 of that of the conventional apparatus.

[Embodiment 7]

In the present example, investigation is made into the most effective radio frequency electric power applied to the auxiliary electrode for realizing a uniform self-bias potential by the position relationship (height relationship) between the surface of the first electrode and the front surface of the auxiliary electrode.

Other features of the present embodiment are identical to those of embodiment 1.

FIG 13 is graph showing changes in the radio frequency electric power, which is applied to the auxiliary electrode and required to uniformize a self-bias potential according to the difference in the height between the upper surface of first electrode and the upper surface of the auxiliary electrode.

When the height of the upper surface of the first electrode and the height of the upper surface of the auxiliary electrode were equal to each other, the radio frequency electric power, which is applied to the auxiliary electrode and required in order to uniformize the self-bias potential, was 100 W. The radio frequency electric power applied to the auxiliary electrode and required to uniformize the self-bias potential increased as the difference in the height was increased, and the radio frequency electric power was 300 W when the height difference was 50 mm.

As shown in FIG 14, in order to prevent the drift of electrons generated on the front surface of the auxiliary electrode from disappearing due to collision with the first electrode , the difference between the height of the surface of the first electrode and the height of the position of the surface of the auxiliary electrode needs to be smaller than the cycloid radius of the electron drift.

By setting the height of the surface of the auxiliary electrode 1401 equal to the surface of the substrate 1403 or setting the difference between the height of the front surface of the auxiliary electrode 1401 and the height of the surface of substrate 1403 equal to or less than 2 mm, the self-bias potential can be equalized with a small radio frequency electric power.

Additionally, using the plasma etching apparatus according to the present

embodiment, a silicon substrate was etched by introducing a mixed gas of C_4F_8, carbon monoxide, oxygen, and xenon into the process chamber and setting the chamber pressure to 5 Pa. The silicone substrate had a silicone oxidization film with a thickness of 1.6 μm formed on the surface thereof, and the diameter was 200 mm. A radio frequency electric power of 1500 W was supplied to the first electrode and a high frequency electric power of 100 W was supplied to the auxiliary electrode. As a result, the uniformity of the etching rate was ±2%.

[Advantages of the Invention]

As explained above, according to the plasma processing apparatus of the present invention, uniformization of the density of the generated plasma with respect to the surface of the substrate and uniformization of the self-bias potential can be attempted without rotating the magnetic field applying means independently of the shape of the upper electrode and the distance thereof while maintaining the pressure distribution on the substrate uniform, and, thereby, the etching process without a charge up damage or the sputtering process which is uniform with respect to the substrate and does not generate a stress can be performed.

Additionally, a plasma processing apparatus having a high radio frequency electric power efficiency can be realizable by covering the surface of the auxiliary electrode by an insulating material.

Further, a plasma processing apparatus having a high radio frequency electric power efficiency can be realizable by equalizing the level of the surface of the substrate placed on the first electrode and the level of the front surface of the auxiliary electrode or setting the difference of the heights to less than ±2 mm.

Additionally, a plasma processing apparatus with a small electric power, a small installation volume and a small magnetic field leakage can be realized by using a dipole magnet-ring as the magnetic field applying means.

Additionally, a plasma processing apparatus in which a chamber wall is prevented from being sputtered can be realized by setting a frequency f1 of a radio frequency applied to the first electrode and a frequency f2 of a radio frequency applied to the auxiliary electrode equal to each other and differentiating phases from each other.

Furthermore, a plasma processing apparatus in which a consumption of the auxiliary electrode is suppressed is realized by setting a frequency f2 of a radio frequency applied to the auxiliary electrode higher than a frequency f1 of a radio frequency applied to the first electrode (f2>f1).

[Brief Description of the Drawings]

FIG. 1 is a cross-sectional schematic diagram of a plasma processing apparatus according to embodiment 1 in which an auxiliary electrode is implemented and drifts of plasma electrodes from a front surface to a back surface of the auxiliary electrode and from the back surface to the front surface of the auxiliary electrode occur.

FIG. 2 is a perspective view of a first electrode and an auxiliary electrode according to embodiment 1 viewed from an upper N-pole of an applied magnetic field.

FIG.3 is a cross-sectional schematic diagram of a plasma etching apparatus according to embodiment 1 that implements an auxiliary electrode and causes drifts of plasma electrodes from the front surface to the back surface of the auxiliary electrode and from the back surface to the front surface of the auxiliary diagram to be generated.

FIG. 4 is a plane view of the auxiliary electrode according to embodiment 1.

FIG. 5 is a plane view showing an auxiliary electrode that is divided into 4 according to embodiment 1.

FIG. 6 is a graph showing a self-bias potential measured in the plasma placed on a substrate according to embodiment 1.

FIG. 7 is a graph showing an ion current density measured in the plasma placed on the substrate according to embodiment 1.

FIG. 8 is a cross-sectional schematic diagram of a plasma etching apparatus according to embodiment 2 that implements an auxiliary electrode and causes drifts of plasma electrodes from a front surface to a back surface of the auxiliary electrode and from the back surface to the front surface of the auxiliary electrode to be generated.

FIG. 9 is a cross-sectional diagram of an auxiliary electrode according to embodiment 3.

FIG. 10 is a graph showing a radio frequency electric power applied to an auxiliary electrode, which can make a self-bias potential the most uniform, according to embodiment 3.

FIG. 11 is a graph showing an amount of sputtering at a chamber wall according to embodiment 4.

FIG. 12 is a graph showing an amount of consumption of the auxiliary electrode according to embodiment 5.

FIG. 13 is a graph showing a radio frequency electric power applied to the auxiliary electrode that is able to equalize the self-bias potential distribution most effectively according to embodiment 6.

FIG. 14 show side views illustrating the relation between a height of the auxiliary electrode and the drift of electrodes according to embodiment 6.

[Description of Reference Symbols]

101	substrate
102	first electrode
103	magnetic field applying means
104	auxiliary electrode
105	front surface of auxiliary electrode
201	substrate
202	first electrode
203	auxiliary electrode
204	drift of electrodes from back surface to front surface of auxiliary electrode
205	drift of electrodes from front surface to back surface of auxiliary electrode
206	drift of electrodes at back surface of auxiliary electrode
206	drift of electrodes at surfaces of substrate and auxiliary electrode
301	chamber
302	exhaust means
303	gas introduction means
304	first electrode
305	matching circuit
306	radio frequency power supply
307	second electrode
308	substrate
309	auxiliary electrode
310	matching circuit
311	radio frequency power supply
312	magnetic field applying means
501	division distance of auxiliary electrode
801	chamber
802	exhaust means
803	bas introduction means
804	first electrode
805	matching circuit
806	radio frequency power supply
807	substrate
808	auxiliary electrode
809	matching circuit

810	radio frequency power supply
811	magnetic field applying means
812	second electrode
813	substrate
814	matching circuit
815	radio frequency power supply
901	auxiliary electrode
902	insulating material
1401	auxiliary electrode
1402	first electrode
1403	substrate
1404	drift of electrodes at front surface of auxiliary electrode
1405	drift of electrode at surface of substrate